

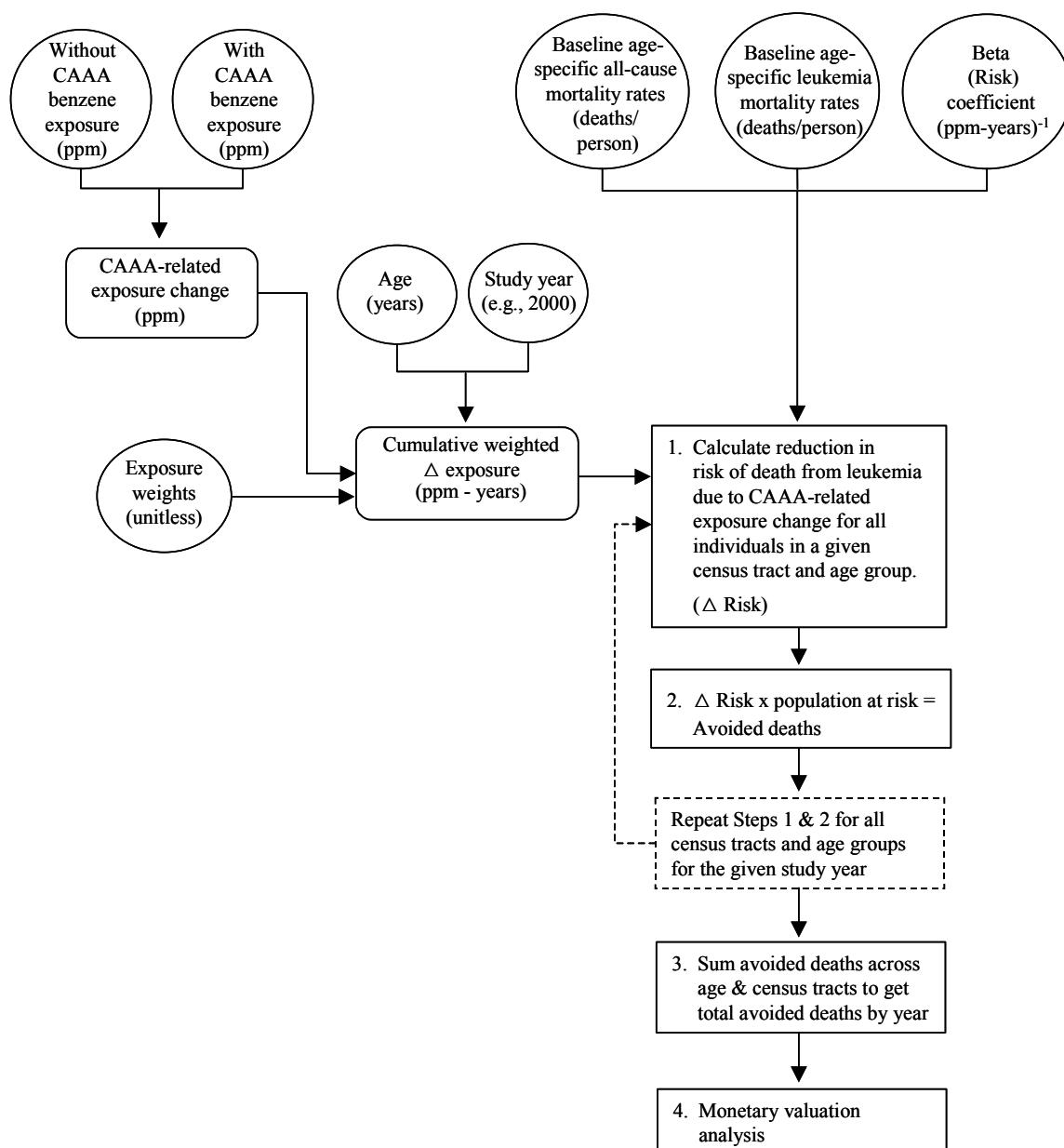
APPENDIX D | LIFE TABLE MODEL EQUATIONS

Figure D-1 provides an overview of the life table model.¹ The model involves calculating cumulative exposure estimates for each five-year age group in each census tract in each study year, which consists of a sum of previous exposure. The previous exposures are weighted differentially, depending on their influence on leukemia mortality rates. These cumulative weighted exposures are used to calculate the difference in risk of dying from leukemia between the *With-* and *Without-Clean Air Act Amendment (CAAA)* scenarios. The risk calculations are then repeated for each census tract and age group combination. The resulting risk values are then multiplied by the population in that census tract to calculate an estimate of avoided deaths from leukemia. Next, we summed avoided deaths across all age groups and census tracts to calculate an estimate of total cumulative avoided deaths by study year and across the entire study period. We then used the estimates of avoided deaths to calculate the monetary benefits related to CAAA-related reductions in benzene exposure.

The model begins with the raw exposure data from HAPEM6 and creates a cumulative weighted exposure measure for each age group in each census tract for each study year (e.g., 2000). This was done by first subtracting each raw five-year average exposure value under the *With-CAAA* scenario for each five-year age group in each census tract from the raw five-year average exposure value under the *Without-CAAA* scenario for the same five-year age group in the same census tract to get a “delta exposure” value, which represents the CAAA-related exposure change.

¹ Figure D-1 and equations presented below assume that the model is run with leukemia mortality rates. The model can also be run with leukemia incidence rates, using the same dose-response slope factor. The difference between these two runs represent an estimate of non-fatal cases of leukemia.

FIGURE D-1: LIFE-TABLE MODEL OVERVIEW



Note: This flowchart assumes the model is being run with leukemia mortality data. The model can also be run with leukemia incidence data. The difference between the model results for these two runs represents an estimate of avoided non-fatal cases of leukemia.

Equation D-1:
$$\Delta e_{i,j,k} = n_{i,j,k} - c_{i,j,k}$$

Where:

$\Delta e_{i,j,k}$ (ppm) = the difference in raw exposure between the *Without-CAAA* scenario and the *With-CAAA* scenario for age group i in period j in census tract k ;

$n_{i,j,k}$ (ppm) = raw exposure value under the *Without-CAAA* scenario for age group i in period j in census tract k ; and

$c_{i,j,k}$ (ppm) = raw exposure value under the *With-CAAA* scenario for age group i in period j in census tract k .

We then created a historical exposure profile for each age group for each five-year period in each census tract to get a cumulative weighted exposure value representing the difference between the *With-* and *Without-CAAA* scenarios for each age in each five-year period in each census tract.

Equation D-2:
$$\Delta E_{i,j,k} = \sum (\Delta e_{i,j,k} \times w_t)$$

$$j = \max(j-i^*, 1995) \text{ to } j; i = 0 \text{ to } i; \text{ and } t = 0 \text{ to } j - \max(j-i, 1995)$$

* i represents the starting age of the age group. For example, age group 5 includes those aged 5-9.

Where:

$\Delta E_{i,j,k}$ (ppm-years) = cumulative weighted exposure representing the difference between the *With-* and *Without-CAAA* scenarios for age group i in period j in census tract k ;

$\Delta e_{i,j,k}$ (ppm) = raw exposure data representing the difference between the *With-* and *Without-CAAA* scenarios for age group i in period j in census tract k ; and

w_t (unitless) = weight corresponding to a given value of t .²

² The weighting function took on the following form: $w(t) = (t/K^2) \exp(-t/K)$. Where: t = the number of years prior to the current year; and K = number of years prior to the current year when the weight reaches its maximum (this also represents the latency estimate).

We then combined the cumulative weighted Δ exposure calculated above with baseline all-cause and leukemia mortality rates and the dose-response slope factor from the selected epidemiologic study to calculate the risk of dying from leukemia in a given five-year period. Equations D-3 and D-4 below are a function of the relative ratio of leukemia deaths to all deaths and the probability of dying in a given five-year period, conditional on survival up to the five-year period for a Baseline scenario (no additional benzene exposure) or an Exposed scenario (with additional exposure to benzene).

Baseline

Equation D-3:
$$R_i^o = \alpha_i / \delta_i \times S(1,i) \times (1 - q_i)$$

Where:

R_i^o = baseline risk of leukemia in the absence of additional benzene exposures for age group i ;

α_i (deaths/person) = baseline leukemia mortality rate for age group i (county-specific);

δ_i (deaths/person) = baseline all-cause mortality rate for age group i (county-specific);

q_i = probability of surviving through age group $i = (\exp(-5 \times \delta_i))$;

$1 - q_i$ = probability of dying while in age group i ;

$S(1,i)_j$ = probability of surviving up to age group i in period j . This is the product of the probabilities of surviving each prior age ($q_1 \times q_2 \times \dots \times q_{i-1} = S(1,i)$) with $S(1,1) = 1.0$. Can be calculated by multiplying $S_{i-1,j-1}$ and q_{i-1} .

Exposed

Equation D-4:
$$R_{i,j,k}^e = h_{i,j,k} / h_{i,j,k}^* \times S(1,i)_{j,k} \times (1 - q_{i,j,k})$$

Where:

$R_{i,j,k}^e$ = risk of leukemia due to benzene exposure for age group i in period j in census tract k ;

$h_{i,j,k}$ (deaths/person) = exposed leukemia mortality rate for age group i in period j in census tract $k = \alpha_i (1 + \beta \Delta E_{i,j,k})$;

Where:

α_i (deaths/person) = baseline leukemia mortality rate for age group i (county-specific);

β (ppm-years)⁻¹ = risk coefficient from epidemiologic study;

$\Delta E_{i,j,k}$ (ppm-years) = difference between the cumulative weighted exposure for the *With-* and *Without-CAAA* scenarios for age group i in period j in census tract k ;

$h_{i,j,k}$ * (deaths/person) = exposed all-cause mortality rate for age group i in period j in census tract $k = \delta_i + (h_{i,j,k} - \alpha_i)$;

Where:

δ_i (deaths/person) = baseline all-cause mortality rate for age group i (county-specific).

$q_{i,j,k}$ = probability of surviving through age group i in period j in census tract $k = (\exp(-5 \times h_{i,j,k}^*))$;

$1 - q_{i,j,k}$ = probability of dying while in age group i in period j in census tract k ;
and

$S(1,i)_{j,k}$ = probability of surviving up to age group i in period j in census tract k ..
This is the product of surviving each prior age group ($q_{0,\max(j-i,1995),k} \times q_{1,\max(j-i,1995)+1,k} \times \dots \times q_{i-1,j-1,k} = S(1,i)_{j,k}$) with $S(1,1)_{j,k} = 1.0$. Can be calculated by multiplying $S_{i-1,j-1,k}$ and $q_{i-1,j-1,k}$.

To calculate the risk due to the additional benzene exposures experienced under the Without CAAA scenario, we subtracted the baseline risk from the exposed risk, using Equation D-5.

Equation D-5:

$$R_{i,j,k}^e - R_i^o = \Delta R_{i,j,k}$$

Where:

$R_{i,j,k}^e$ = risk of leukemia due to benzene exposure for age group i in period j in census tract k ;

R_i^o = baseline risk of leukemia in the absence of additional benzene exposures for age group i ; and

$\Delta R_{i,j,k}$ = risk of dying from leukemia due to CAAA-related exposures for all individuals in age group I in period j in census tract k .